EXPERIMENTAL INVESTIGATION OF A NEW SOLID WOOD PANEL FOR ROOM TEMPERATURE CONTROL – ANALYSIS OF THE COOLING PERFORMANCE

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ABSTRACT

Wood industry's current economic development shows an increase of selling multilayered solid wood panel products accompanied by a crescent functionalization of those panels. Within an industry driven project an additional functionalization in form of pipe elements for heating and cooling are to be applied to a multilayered solid wood construction. The development of this innovative radiant heating and cooling system requires extensive laboratory analysis. Investigations are focusing on thermal optimization as well as thermal and hygric long-term performance and durability. Previous studies devoted to optimize panel structure during a heating process, enabling efficient heat distribution within the panel as well as to the enclosing room. Whereas, current studies are concentrating on the cooling performance, which was analysed by means of specially manufactured prototypes of a solid wood panel. Laboratory measurements were carried out using a climatic test chamber as well as test benches, equipped with an infrared thermographic camera and several sensors for measuring temperature, relative air humidity, and heat flux density. Climate test chamber measurements are aiming at exploring material performance and stability of selected panel prototypes under defined boundary conditions. The performance of the overall panel system is investigated in specially built test benches, which allow statements to be made about the effectiveness of the radiant heating and cooling system with respect to a defined space. Within this paper measurement procedures of a laboratory panel investigation are described and first results are shown. Main criteria and boundary conditions of the measurement procedure are discussed. Measurement results are evaluated, particularly with regard to formation of condensation and moisture during a cooling load. Significant statements about functionality and cooling performance of the new developed wooden panel for room temperature control are made.

Keywords: solid wood panel, radiant heating and cooling, moisture management of wood, laboratory performance and damage analysis

INTRODUCTION

Radiant heating and cooling systems are an efficient solution for room temperature control. For heating purposes they are preferably installed in floor and wall constructions. With a cooling purpose they are applied to ceiling structures, but also to wall areas. Often, the systems are installed in new buildings or in complex rehabilitation measures. An innovative, sustainable and cost effective variant represents the development of a new radiant heating and cooling system based on a complex multilayered solid wood construction. This panel is suitable, due to the production as a visible wall element, especially for the renovation of existing buildings.

The panel to be developed consists of three wooden layers bonded with melamine-urea-formaldehyde resin and a multilayer composite pipe element which is installed in a middle layer. Figure 1 depicts the structure of an optimized panel chosen from a variation study carried out by Bishara [1]. Its total thickness is 33.4 mm and pipe distance is 80 mm, occasionally 100 mm. For laboratory testing prototypes measuring 800 mm by 800 mm are manufactured whereby pipes with a diameter of 16 mm are arranged in spiral course.

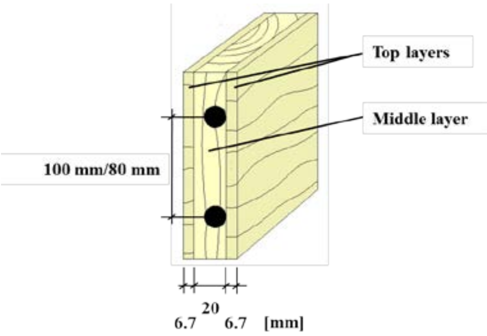

Figure 1: Structure of the wooden tempering system

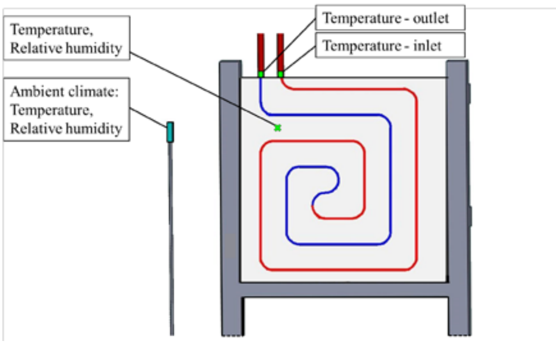

Figure 2: Climate test chamber experiment-measurement setup

Three different panel variants of a prototype were chosen for experimental investigation in laboratory. They differ in choice of material and pipe distance as can be seen in Table 1.

Panel type	Top layer material	Middle layer material	Pipe distance	Experimental investigation
1	Spruce	MDF	8 cm	Climate chamber experiment: long-term cooling
2	Spruce	Spruce	8 cm	Climate chamber experiment: complex cooling
3	Spruce	Spruce	10 cm	Test bench

Table 1: Panel variants for laboratory investigation

METHOD

Measurement setup of a climate test chamber experiment

1 - Long-term cooling

Panel type 1 was installed in a climate test chamber in order to achieve statements about the hygrothermal material strain during a cooling period. This panel variant comprises an MDF middle layer. A cooling period was defined with an ambient temperature of 28°C and an ambient relative air humidity (RH) of 65%. During a loading duration of 23 days, the solid wood panel was operating with a constant flow temperature of 16°C.

The measurement setup is represented in Figure 2. An insulation layer was installed in the panel`s rear area in order to restrict heat flow to one direction. Ambient climatic conditions were monitored with a negative temperature coefficient thermistor sensor (NTC) ensuring an accuracy of ± 0.1 K, and a capacitive sensor with an accuracy of ± 2 % RH. Temperature inlet and outlet were recorded with NTC sensors directly on the pipe`s surface. Additionally, the pipes were thermally isolated with polyethylene to avoid interaction with ambient climate. The hygrothermal behavior inside the panel was monitored with capacitive and NTC sensors.

2 - Complex cooling

A panel type 2 was investigated in a more complex cooling experiment. Boundary conditions for this cooling experiment are represented in Table 2, defined as a sequence of summer day and night conditions. The measuring run started with a day mode, followed by a night mode, and a repetition of both phases. During day mode, ambient temperature was set to 28°C, and flow temperature to 16°C. Night mode was defined as night shut down of the cooling function and an ambient temperature of 20°C. Relative humidity was supposed to be 65% during the whole measuring circle.

Mode	Duration	Ambient climate		Temperature pipe element
		Temperature	Relative humidity	
Day mode	20 h	28°C	65%	16°C
Night mode	24 h	20°C	65%	-
Day mode	24 h	28°C	65%	16°C
Night mode	93 h	20°C	65%	-

Table 2: Boundary conditions of a complex cooling experiment

Measurement setup of the test bench experiment

Figure 3 depicts a test facility, comprising an air volume of 1 m³, for the installation of a panel in a wall area. A wall construction was built on one of the room`s side walls consisting of a brick layer (thickness 117 mm) and a layer of capillary-active insulation (thickness 100 mm). In the brick layer`s rear area, an additional tempering system was installed, generating defined surface temperatures. A panel type 3 to be monitored was installed in connection to the internal insulation layer.

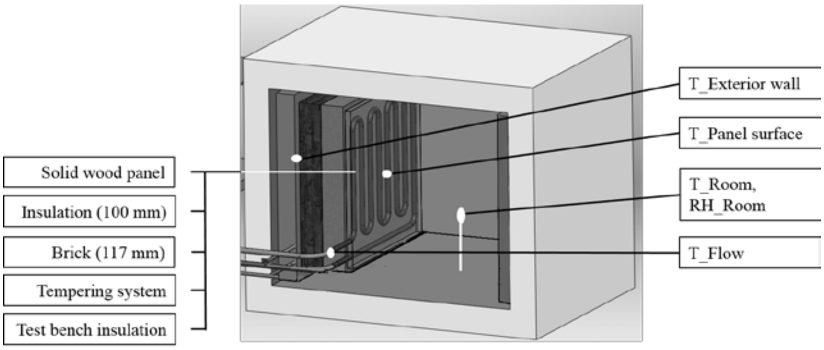

Figure 3: Test bench - experimental setup

At the beginning of the experiment, a defined temperature of 47°C was set to the brick layer`s outside, until room temperature reached 28°C. Once this temperature was reached, the wooden panel`s pipe system was provided with a flow temperature of 16°C and a cooling process started. The aim was to define that period of time which was needed for reaching a room temperature of 26°C. This value corresponds to the standard internal temperature for the application of cooling systems, according to European Standard EN 1264-3 [2].

Subsequently, the panel operation was driven by a temperature-controlled thermostat. At a temperature set point of 25.5°C the cooling operation switched off automatically, and at a set point of 26.5°C it switched on again. A comparison was made between duration of cooling period and cooling break.

Within the test bench, extensive measuring equipment was installed. Air temperature and relative humidity inside the test stand were measured with NTC and capacitive sensors. NTC sensors were also installed on inlet and outlet of the solid wood panel, directly on the pipe surface, to monitor flow and return temperatures. Temperature in a plane between additional tempering system and wall outside layer (T_Exterior wall) was recorded with an NTC sensor.

The test bench was sealed airtight and sheathed with a 100 mm thick insulation layer. During measurements, this test stand was positioned in a laboratory facility with controlled climatic conditions, which were also monitored with NTC and capacitive sensors.

RESULTS AND DISCUSSION

Climate test chamber experiment

Figure 4 provides measurement results of a long-term cooling period. Ambient temperature was measured at average 28.8°C. Relative humidity ranges slightly between 64% and 69%. Recorded temperature values inside the panel construction are declining very slightly from 24.3°C to 24.0°C. In contrast, related relative humidity values increase throughout the entire cooling period. Cause for this is the hygroscopic property of the wood material, which aspires to take a moisture balance with its environment. In this regard, water vapor diffusion occurs due to a vapor pressure gradient between ambient climate (higher vapor partial pressure) and wood material (lower vapor partial pressure). Due to a high resistance of a radial spruce wood direction to vapor diffusion (measured μ_{dry}-value of 475) this process takes correspondingly long-time. No state of equilibrium has been reached at the end of the cooling experiment.

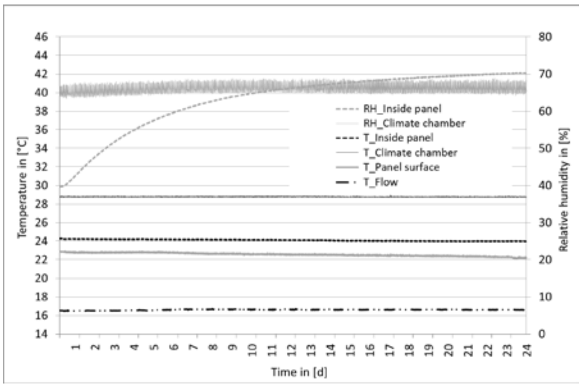

Figure 4: Measurement results of a long-term cooling period

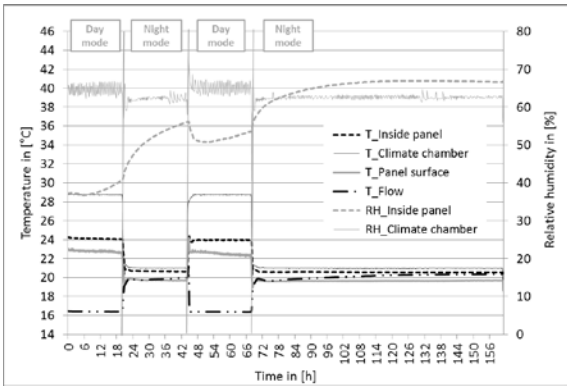

Figure 5: Measurement results of a complex cooling period

In general, a damage-free operation of the panel to an equilibrium moisture content of 95 % RH is assumed, due to capillary property of wooden materials. This threshold is not exceeded in the area around the sensor inside the panel construction.

However, most critical and thus decisive points exist directly above the pipe. At the interface between pipe and wood material, where temperature is lowest, pipe surface temperature is 16.1°C. Thus is resulting in a lower deviation of dew point temperature by 1.8 K (based on the measured humidity value inside the panel). Consequently, a safe system design under given boundary conditions is given only up to a measured relative humidity of 58 %, which is reached already after 5.2 days.

At a measured room climate of 28.8°C and 69% RH, dew point temperature at the panel`s surface is 22.5°C. This value is reached after 13 days of operation. Consequently, moisture damage occurs at the panel`s surface, however in a significantly lower extent as expected. Surface moist occurred only in the area of sensor cables as well as in the area of two larger branches. Additionally, moisture accumulation inside the MDF is assumed, due to a much lower sorption capacity of MDF compared with spruce [3]. However, the pipe course did not become visible on surface and also cracks could not be observed.

Figure 5 shows an excerpt of measurement results from a complex cooling experiment. With the change from day mode to night mode (cooling operation switches off), a temperature drop occurs in the air around the sensor. Thereby saturation of vapour pressure of the air decreases abruptly. Hence, a much lower maximum amount of water vapour particles can be absorbed. This leads to a rapid increase in measured relative humidity. The curve flattens over time during night mode, since temperature does not change further.

However, humidity continues to rise, due to the fact of a partial pressure gradient between wood element and environment. Conversely, saturation vapour pressure rises with heating of the wood material in leap from night mode to day mode. Thus, relative humidity decreases rapidly, as the heated air can now absorb much more vapour particles in relation to its equal volume retarded. After this rapid drop, air humidity increases again steadily.
Within a subsequent longer night phase, relative humidity around the sensor increases constantly, until it has reached a maximum value of 70%. At this point a wood moisture assessment in accordance to Kollmann [4] is performed. Kollmann offers a diagram which is used to derive the moisture content of spruce wood from ambient climatic conditions. Within the experiment, a maximum relative humidity (70 %) faces a temperature of 20.5°C which is resulting in a wood moisture content of 13%. This value is below fiber saturation point of coniferous wood, defined by Niemz [5] at about 30 % and higher.
According to EN 1264 [2], a cooling system design has also to take dew point temperature into account. Flow temperature is supposed to be 1 K above dew point temperature, at minimum. With the given extremal boundary conditions of 28.8°C and 67% RH during a cooling period, dew point temperature is 22.1°C. The present flow temperature (16°C) is thus 6.1 K below required minimum value. Since this dew point value is not exceeded at the panel surface during an entire cooling period of 24 hours (measured minimum value is 22.4°C), no wood damage occurred. There were neither cracks on the panel`s surface, nor became the pipe course visible on the surface.

Test bench experiment

In Figure 6 measured values of an initial cooling process, carried out in a test bench experiment, are shown. After a phase of preconditioning, in which the room was heated to a temperature of 28.2°C, the cooling function was switched on. Cooling down of the tempering fluid to a flow temperature of 16°C took 30 minutes. From that moment on it takes 3.5 hours until room temperature measures 26°C. Throughout the entire duration of the cooling mode relative humidity remains almost constant at 53%, after a slight decrease at the beginning.
Measured values of a further experiment course are shown in Figure 7. A set point for automatic thermostat turn off is measured at 25.4°C. It turns automatically on again at a measured room temperature of 26.5°C. An exact period duration of cooling phases and breaks is readable from these values: on every 2.5 hours of cooling follows a 7 hour break. The panel operation switches itself on, 2.5 times a day in average. This periodic cycle was performed over a period of 4 days.

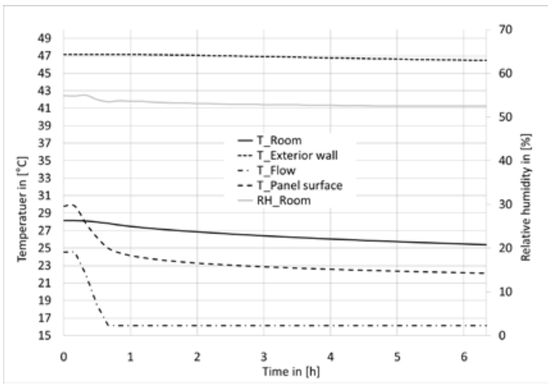

Figure 6: Measurement results of a test bench experiment – initial cooling

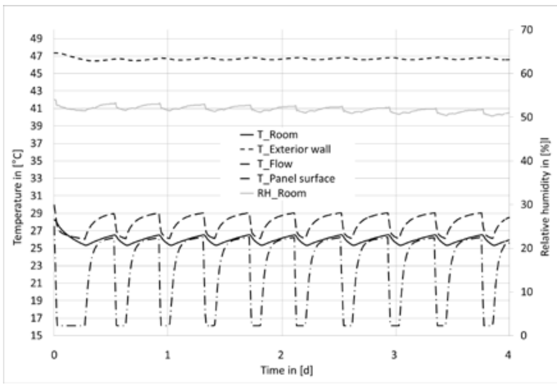

Figure 7: Measurement results of a test bench experiment – automatic switch on/off

Dew point analysis shows that with given boundary conditions of 28.2°C and 54% RH dew point temperature is 18.0°C. Thus, the system is operating 3 K below required flow temperature minimum value, according to EN 1264 [2]. However, moisture damage could not be observed because moisture buffering capacity of a multi-layered solid wood panel within a certain hygroscopic range is even higher than the one of massive wood. An investigation, carried out by Popper [7], shows that equilibrium moisture content of a solid spruce wood panel is varying in dependence on the hygroscopic range. Below 65 % RH it is significantly higher than the one of spruce wood. Above this level, it is significantly below.

CONCLUSION

The cooling performance of an innovative multilayered solid wood panel with functional pipe element in the middle layer was laboratory examined.
An evaluation of climate chamber measurements shows that a panel structure could perform well even during intense climatic loads. Under prolonged hygric stress in combination with lower deviation of dew point temperature, moisture damage of a wooden panel with MDF middle layer could not be avoided. However, a solid spruce wood panel remained free of damage, even after 24 hours operation below dew point temperature.
An investigation of a panel`s cooling performance in connection to a defined space of 1 m³ provides extensive measurement data. Measurement results show that cooling a room with a solid wood panel, although with temporary lower deviation of dew point temperature is possible. Even after a multi-day cooling cycle no damages due to moisture stress were evident. One crucial conclusion is: design criteria according to EN 1264 [2] should not be decisive, rather measured material limits of spruce wood should be considered. For defining these boundaries accurately, further laboratory studies are needed. Subsequently, an analysis of a damage free operation during a long-term test with real climate conditions and user behaviour is necessary.

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